Water Surface Area and Temperature Change Detection Analysis in Lagoons (A Case Study in Puttalam Lagoon, Puttalam)

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Abstract

Puttalam lagoon significantly contributes for the livelihood through fishing for the economically deprived community in Puttalam District, Sri Lanka. Observable anthropogenic activities and rapid urban development cause deterioration of water quality and reduction of surface area of water body. The objective is to study the spatiotemporal changes on the surface area and on surface temperature of lagoon. This study was done using geographic information system and remote sensing approach for the six Landsat (3 TM, 1 ETM and 2 OLI) imageries and Water Ratio Index was applied to extract and quantify the changes in the surface area and spectral radiance approaches to determine the land surface temperature of the lagoon for the period of 1988, 1995, 2001, 2008, 2015 and 2019. The multi temporal map of surface area and surface temperature maps were produced for the change directions. The results revealed a significant decrease in surface area of the lagoon which was nearly 8.7% of its surface area and an increase of temperature by nearly 5.2°C during the period of study. Strong negative correlation (Pearson's correlation coefficient = 0.91) observed at 95% of significance level (p value = 0.01) between the surface area and temperature of lagoon. It is essential to take conservation measures to sustain this lagoon at Puttalam.

Keywords: remote sensing, change detection, land surface temperature, water ratio index, geographic information system.

Introduction

Water bodies are one of the major natural resources in the ecosystem and need for ecosystem balance. Anthropogenic activities significantly affect the quality and quantity of water in the natural water bodies that lead to the water scarcity. The main objective of this study is to detect the changes in the surface water area of the Puttalam lagoon and land surface temperature at the lagoon area during past three decades (1988 to 2019) using remote sensing and GIS technology, to help to conserve the natural water bodies and to proceed with sustainable management activities.

Materials and Methods

The study area, Puttalam Lagoon is located in the North Western Province of Sri Lanka at 7°44'46 – 8°35'60 north and 79°48'25 – 79°49'17 east, which is one of the largest inland brackish wetlands in Sri Lanka.

Puttalam lagoon area and surface temperature change detection were done by using six satellite imageries that downloaded from the United States Geological Survey (USGS) Earth explorer shown in table 1. Landsat images downloaded during the period from January to February to avoid the seasonal changes and all the images were geometrically, atmospherically and radiometrically corrected. After that images were ready to extract the required data. Water ratio indices (WRI) and Land surface temperature (LST) were extracted to find out the water features to detect the area of lagoon and the surface area of lagoon respectively. Mapping and distribution analysis were done by using Quantum GIS 3, IBM SPSS Version 25 and MS office.

Table 1: Specification of the satellite data

Year	Sensor	Path/row	Resolution
1988	TM	142/054	30
1995	TM	142/054	30
2001	TM	142/054	30
2008	ETM	142/054	30
2015	OLI_TIRS	142/054	30
2019	OLI_TIRS	142/054	30

Multi-band approach for mapping shallow and turbid coastal lagoons was reported as the most accurate method (El-Asmar, et al., 2013). Water Ratio Index was used in this study. The spectral reflectance of Green band, Red band, Near Infrared band and Middle Infrared band, as shown in the equation for in TM and ETM satellite imageries (Shen, and Li, 2010) developed to extract a water feature depending on the normalized relationship between the reflection in the green and the Near Infrared from Landsat satellite images.

$$WRI = \frac{Green + Red}{NIR + MIR}$$

WRI was determined in Landsat 8 OLI image as following equation (Acharya, et al., 2017)

$$WRI = \frac{Green + Red}{NIR + SWIR1}$$

After geometric, atmospheric and radiometric correction, the land surface temperature for the year 1988, 1995, 2001, 2008, 2015 and 2019 were detected by using Landsat thermal bands. Initially Landsat sensors collect and store thermal data as digital numbers (DN) values (Chander, et al., 2009). Conversion of DN values into LST for Landsat thematic mapper (TM) and enhanced thematic mapper (ETM) has followed three step process while Landsat operational land imager (OLI) images has followed seven step process as shown below,

LST for Landsat TM and ETM images initially the DN of band 6 was converted to spectral radiation (SR) luminance by the equations (USGS**).**

$$SR = \left(\frac{Lmax - Lmin}{QCALmax - QCALmin}\right) \times (QCAL - QCALmin) + Lmin$$

Then calculated SR was converted to LST in degree Celsius using equation,

$$LST = \frac{K_2}{\ln(\frac{K_1}{SR} + 1)} - 273.15$$

In this study, the following steps were followed to determine the LST from Landsat 8 OLI thermal bands (Mohsen, et al., 2018). Thermal infrared sensor band 10 and 11 were used to covert the raw images to spectral radiance image by following equation,

$$SR = \left(\frac{Lmax - Lmin}{QCALmax - QCALmin}\right) \times (QCAL) + Lmin$$

Then calculated SR was converted to brightness temperature (BT) in degree Celsius using the equation,

$$BT = \frac{K_2}{\ln(\frac{K_1}{SR} + 1)} - 273.15$$

Normalized difference vegetation index (NDVI) was used to estimate the land surface temperature for Landsat 8 images.

$$NDVI = \frac{NIR - R}{NIR + R}$$

Value Proportion of Vegetation (PV) using the NDVI and Land surface emissivity (LSE) were calculated,

$$PV = \frac{NDVI - NDVImin}{NDVImax + NDVImin}$$

$$LSE = 0.004 \times PV + 0.986$$

Finally, land surface temperature was calculated by the following equation

$$LST = \frac{BT}{\{1 + \left(\frac{\lambda BT}{\rho}\right) \times \ln(LSE)\}}$$

ρ calculated as,

$$\rho = h \times \frac{c}{\sigma}$$

where, BT – Brightness temperature, c – Velocity of light, h – Planck's constant, K_1 – Calibration constant 1, K_2 – Calibration constant 2, Lmax – Spectral radiance scaled to QCALmin, Lmin – Spectral radiance scaled to QCALmax, LST – Land surface temperature, NDVI – Normalized difference vegetation index, NIR – Near infrared, QCAL – Quantized calibrated pixel value in DN QCALmax – Maximun quantized calibrated pixel value (corresponding to Lmax) in N, QCALmin – Minimum quantized calibrated pixel value (corresponding to Lmin) in DN, R – Red, SR – spectral radiance, λ – Wavelength of emitted radiance, σ – Boltzmann constant

Images digitizing tool was used to separate the study area to build the mask. Then mask was used to extract the entire study area from the images. Threshold values for WRI indices were assigned to all images by trial and error and visual inspection to extract water feature from the images. Then water pixels were collected to estimate the surface area of the lagoon in each image. At the same time land surface temperature maps also prepared for 1988, 1995, 2001, 2008, 2015 and 2019. The relationship between the estimated surface water area and estimated land surface temperature was studied through correlation analysis.

Results and Discussion

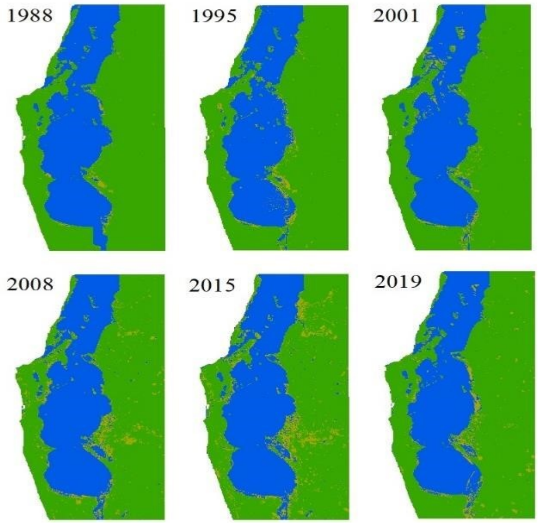

Figure 1: Water ratio index for Puttalam lagoon in 1988, 1995, 2001, 2008, 2015 and 2019

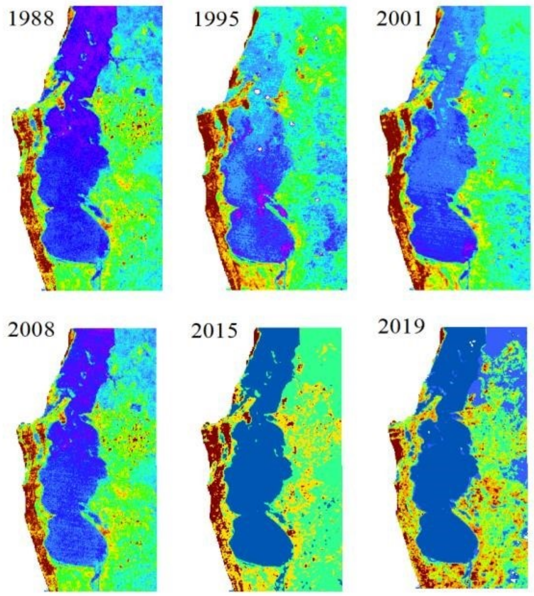

Figure 2: Land surface temperature for Puttalam lagoon in 1988, 1995, 2001, 2008, 2015 and 2019

The multi-temporal maps of the lagoon surface area were produced to detect changes as shown in figure 1 and the multi temporal maps of temperature shown in the figure 2 of the l study years of 1988, 1995, 2001, 2008, 2015 and 2019. Significant change has observed in the surface area of Puttalam lagoon and land surface temperature during the study period from 1988 to 2019 as shown in figure 2 and 3. The study revealed that the lagoon lost nearly 8.65% of its total surface water area over the study period and the temperature reduction of 0.1%. The surface water area of the lagoon was identified by about 3557432 m^2 in 1988 and 3249876 m^2 in 2019.

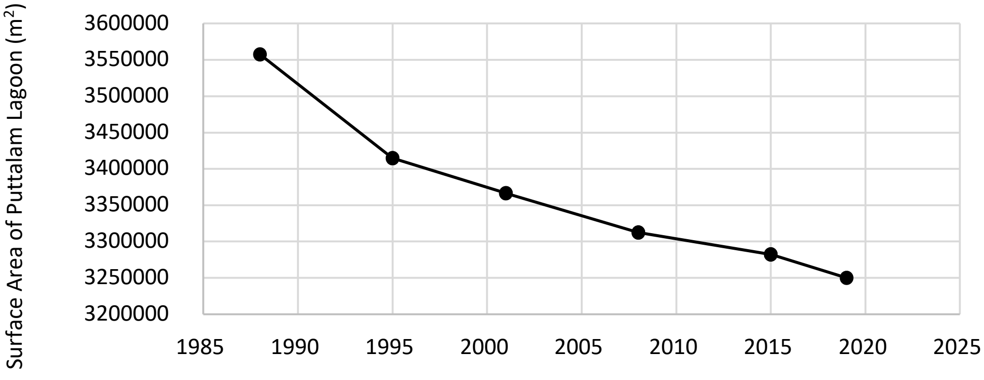

Figure 3: Changes in surface water area of Puttalam Lagoon for the period from 1988 to 2019

Figure 3 shows the trend of changes in area in lagoon surface water area and figure 4 shows the trend of changes in the temperature from 1988 to 2019. It also shows that a significant decrease in water area of the lagoon and increases in the land surface temperature occurred from 1988 to 2015.

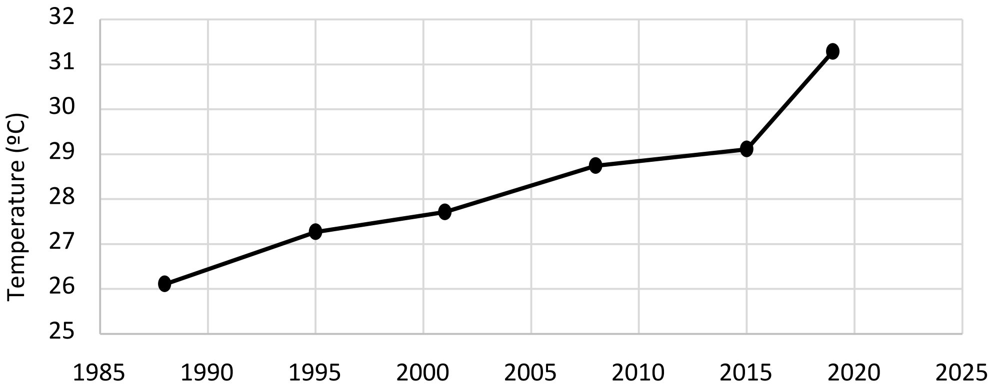

Figure 4: Changes in land surface temperature of Puttalam Lagoon for the period from 1988 to 2019

Table 2 shows the surface water area and the land surface temperature of the lagoon, and the changes occurred in the area and temperature between successive years.

-0.91 Pearson's correlation coefficient was observed at 95% significance level (p value = 0.01) between surface area and the average land surface temperature. It shows the strong negative correlation at 95% significance level.

Table 2: Surface area and temperature of Puttalam lagoon and its changes.

Year	Surface area (m^2)	Changes of surface area (m^2)	Average land surface temperature (°C)	Changes of land surface temperature (°C)
1988	3557432	–	26.11	–
1995	3414708	142724	27.27	1.16
2001	3366578	48130	27.72	0.45
2008	3312345	54233	28.75	1.03
2015	3282303	30042	29.11	0.36
2019	3249876	32427	31.29	2.18

Conclusion

This study used remote sensing and geographic information system to investigate the change detection of Puttalam lagoon for the period of 1988, 1995, 2001, 2008, 2015 and 2019. Water ratio index water indices was applied to extract water feature from remote sensing imageries and spectral radiance was used to extract the land surface temperature. Results showed that the reduction in surface water area of the lagoon is significant, about 8.65% and 0.1% of temperature increase in the land surface. The strong negative correlation observed with the 0.91 Pearson's correlation coefficient at 95% of significance level (p value = 0.01*). Actions should be taken to remove encroachment and waste disposal to minimize the impact on the lagoon environment. This study also showed the ability of remote sensing and geographic information system to monitor the changes on the natural resources as sustainably and effectively.

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